DOCUMENT RESUME

ED 414 206		SE 061 022

AUTHOR	Mashhadi, Azam
TITLE	Figurative Thinking and the Nature of Physics.
PUB DATE	1997-06-00
NOTE	27p.; Paper presented at the Annual International Conference on Thinking (7th, Singapore, June 1-6, 1997).
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Concept Formation; Creative Thinking; Elementary Secondary Education; *Figurative Language; Foreign Countries; *Metaphors; *Physics; Questionnaires; Science Education; *Student Attitudes; Thinking Skills
IDENTIFIERS	Analogies

ABSTRACT

Scientific language is not simply for recording facts but it is also an instrument of thought. It has a central role in not only developing a sense of social identity for members of the scientific community and students in the classroom but also in inculcating views on the nature of science and reality itself. Physicists have created a language in which the fundamental components and symmetries of the world cannot be observed. It is not the case that there is a non-metaphorical physics that has to be made intelligible using figurative language--analogy and metaphor are inherent in the nature of physics. Figurative thinking lies at the heart of scientific thinking. Some results of an empirical investigation of students' conceptions of figurative language are described following an analysis of the nature of metaphors, analogies, and models. Contains 55 references. (Author/NB)

Paper presented at the *7th International Conference on Thinking (Borderless Thinking: Creating a Global Learning Society)* [Singapore, 1-6 June 1997].

Title: Figurative thinking and the nature of Physics

Azam MASHHADI
Affiliation: Department of Educational Studies, University of Oxford, 15 Norham Gardens, Oxford OX2 6PY, United Kingdom
e-mail: azam.mashhadi@edstud.ox.ac.uk

Abstract

> But the greatest thing, by far, is to be a master of metaphor. It is the one thing that cannot be learnt from others; and it is also a sign of genius since a good metaphor implies an intuitive perception of similarity of dissimilars. Through resemblance, metaphor makes things clearer.
> Aristotle (Poetics)

Scientific language is not simply for recording 'facts', but is also an instrument of thought (Solomon, 1986). It has a central role in not only developing a sense of social identity for members of the scientific community and students in the classroom but also in inculcating views on the nature of science and 'reality' itself (Zeidler and Lederman, 1989). Physicists have created a language in which the fundamental components and symmetries of 'the world' cannot be observed. It is not the case that there is a non-metaphorical physics that has to be made intelligible using figurative language - analogy and metaphor are inherent in the nature of physics.

Figurative thinking lies at the heart of scientific thinking. Following an analysis of the nature of metaphors, analogies and models some results of an empirical investigation of students' conceptions of figurative language are described.

Category of presentation: Paper

Strand: Education

Key words: figurative thinking, physics, students' conceptions

Bio-data
Azam MASHHADI's doctoral thesis, at the University of Oxford (UK), addressed the question of *What is the nature of the understanding of the concept of 'wave-particle duality' among Advanced level Physics students?* Following degrees in Physics and Astrophysics (University of London) and Astronomy (University of Sussex) he taught for several years at a college in London (UK) before completing a MSc in Educational Research Methodology (Oxford). His research interests include student learning, teacher education, the use of IT in education, research methodology, and philosophy of science education.

> As Bohr said,'When it comes to atoms, language can only be used as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images.' The same is true of cosmological models, curved spaces and exploding universes. Images and analogies are the key .... Not you, not I, not Einstein could interpret the universe in terms wholly related to our senses. Not that it is incomprehensible, no. But we must learn to ignore our preconceptions concerning space, time and matter, abandon the use of everyday language, and resort to metaphor. We must try to think like poets.
> Tolstoy (1990: 16)

1. Introduction

> A world ends when its metaphor has died.
> Archibald MacLeish

In recent years there has been increasing attention to the importance of language in the learning of science, based on the generally presumed close relationship between language and concept learning. The teaching of science occurs almost entirely through the use of language, both spoken and written. Scientific language is not simply for recording 'facts', but is also an instrument of thought (Solomon, 1986). It has a central role in not only developing a sense of social identity for members of the scientific community and students in the classroom but also in inculcating views on the nature of science and 'reality' itself (Zeidler and Lederman, 1989). The science educator Guy Claxton (1997: 72) points out that:

> ... the languages of science are saturated with metaphors and symbols borrowed and adapted from the vernacular. Scienctific maps, like all maps, are works of human invention, and they must needs borrow from the known to chart the unknown. Whether it be atoms as billiard balls, electric current as a teeming crowd of electrons, or *Homo sapiens* as a naked ape, scientific theories are closer to poetry and art than the rhetoric of science frequently admits.

The philosopher of language Max Black (1962 : 242) argues that:

> ...perhaps every science must start with metaphor and end with algebra; and perhaps without the metaphor there would never have been any algebra.

Similarly Douglas Berggren (1962: 472) points out that:

> ...truly creative and non-mythic thought, whether in the arts, the sciences, religion, or metaphysics, must be invariably and irreducibly metaphorical.

Lakoff and Johnson (1980) argue that all language is metaphorical and that it is only possible to speak of one thing in terms of another. The philosopher Richard Rorty (1980; 1989) argues that the history of science can be described as consisting of the literalisation of metaphors. The history of science should be perceived not as a history of discovery but as a history of metaphor. Ideas in science originate as metaphors, and retain their richness and ambiguity as the theory develops. However as the theory/metaphor leads to more and more settled findings then the life and range of possibilities gradually reduce, leaving so-called 'literal truths' and less and less research to be carried out. Individuals become so familiar with it that it ceases to be experienced as a metaphor (Young, 1993).

Physicists have *created* a language in which the fundamental components and symmetries of 'the world' cannot be observed. For instance, quarks are said to come in three colours. The weak force is described as changing the flavour of quarks by rotating them in flavour space; the colour force changes the colour of quarks by rotating them in colour space. The colour force is carried by gluons. The strong force, which holds protons and neutrons together, is described as a residue of colour interactions occurring inside protons and neutrons.

The word 'inertia' does not refer to an object or entity, but to a concept somehow acquired from the experience of trying to move heavy things (Wellington, 1983). Words for unobservable entities such as 'electron' cannot be derived from direct experience and can only have 'meaning' in a theoretical context. As Wellington (1983: 770) expresses it:

> The meaning of 'electron' somehow belongs to a theoretical world of nuclei, atoms, electric fields, shells and orbits - an imaginary, almost make believe world to pupils starting science. Yet 'electron' *can* acquire meaning, just as the words in a far-fetched fairy tale do.

Concepts embody generalisations from particulars, e.g. wave, particle. Each is a word representing an idea. To be even more precise, a concept is the relationship between the word (or symbol) and an idea or conception. We all make use of concepts. some concepts are shared by all groups of people within the same culture, e.g. love, hate, child. Other concepts are used only by particular subgroups, e.g. the theoretical particle physicist would make use of quarks, gluons, and quantum chromodynamics.

Science has constructed 'models of reality', which attempt to provide an unified systematic 'picture' that is able to not only describe a range of seemingly unrelated phenomena but is able to predict unknown phenomena and direct further inquiries about the world. The accompanying public critical discussion of claims made by scientists is facilitated by the use of formal representations and precision in the use of language. This leads to different meanings being attached to words that are common to both science and everyday language (e.g. work, power etc.). As Einstein and Infeld (1938) expressed it:

> Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions.

People use concepts to impose some meaning on the world - 'reality' is given sense, order and coherence. In arguing against treating language as a set of labels on a pre-existing or 'objective world' the linguist Edward Sapir (1929: 162) comments:

> It is quite an illusion to imagine that one adjusts to reality without the use of language and that language is merely an incidental means of solving specific problems of communication or reflection. The fact of the matter is that the 'real world' is to a large extent unconsciously built up on the language habits of the group. No two languages are ever sufficiently similar to be considered as representing the same reality. The worlds in which different societies live are distinct worlds, not merely the same world with different labels attached.

For the child language is initially an external reality to be mastered. However external language is itself a social construction. Curtis and Miller (1988: 62) point out that:

> ... a child who experiences difficulties in the use of spoken or written language is likely to have additional difficulties in understanding and using the rather specialised vocabulary of the sciences. On a deeper level, language plays a crucial role in the child's ability to construct meaning; the learning of abstract scientific concepts depends both on the child's ability to use language to explore his/her existing conceptions and on the richness of the word-and the idea-associations which the child has with the particular scientific ideas involved.

2. How can language be used?

The seventeenth-century scientific revolution was accompanied by the conception of an 'ideal language'. This would enable scientists to read off from the 'book of nature' the true science

that exactly expresses reality, i.e. scientific realism and a correspondence theory of truth. Galileo asserted that the universe is a 'great book ... written in the language of mathematics'. Leibniz searched for the ideal language, the 'characteristica universalis', which would correspond exactly to the language in which nature is written. Meaning changes of various kinds are, however, pervasive in language.

Developments in the philosophy of science (c.f. Kuhn, Popper etc.) have had implications for the changing meanings associated with words such as 'observe', 'perceive', 'discover', 'theory' and 'facts'. As Clive Sutton (1992) points out the meanings of words in science change over the years. However, there appears to be a strongly held belief that physics is not a product of human beings, but rather an acceptance of the epistemology that scientific knowledge comes from 'things' rather than from people.

Sutton (1992) argues that the two ways in which language can be used can easily lead to two sets of beliefs about what language is, and how it works: language as a labelling system and language as an interpretive system. Words are often used as labels for things, rather than instruments of interpretation. The ideas of science become transformed into arbitrary information to be learned. Physics continuously generates new concepts by interpretive effort. Repetition results in their initial use in new thoughts giving way to their treatment as ordinary items. Intangibles like 'electrons' and 'atomic orbitals' become more substantial and 'thing-like' - interpretations assume the status of labels. Sutton (1992: 102) advocates emphasising the importance of developing ideas and testing ideas, and showing the provisional nature of theories by using 'as-if' phrasing:

> It is hard to know what "really" happens in this television tube but it is *as if* tiny charged particles were emitted from this part here....

Over the last fifteen years there has been considerable interest in the student's perceptions of phenomena taught in science classes. There has been research in such areas as energy, motion, the particulate nature of matter, electricity, and light. Language allows students to communicate their understanding of a subject.

If the students' ideas are perceived to be in conflict with what is thought to be the 'right answer' as held by the scientific community they have been variously described as: students' conceptions, misconceptions, preconceptions, children's' science, alternative conceptions, alternative frameworks. The label applied depends upon the researcher's own views of the nature of knowledge (Gilbert and Watts, 1983). Such 'alternative conceptions' are often strongly held, very resistant to change and can impede further learning (White and Gunstone, 1989). 'Surface learning' can result in students performing well in a test, yet not undergoing any meaningful change in their conceptions of a particular phenomena.

Science education has been structured around what is perceived to be the scientist's concepts of the natural world. The *tabula rasa* conception of the learner has come to be replaced by many researchers with the concept of the learner who brings to the classroom a complicated body of personal knowledge and understanding (Ausubel, 1968; Driver, 1981; Erickson, 1979; Osborne and Gilbert, 1980; Pope and Gilbert, 1983). During lessons examples used to illustrate a concept may convey a totally different meaning to the student, the net result being that the actual outcome may well be different from the intended (Anderson, 1986).

3. Figures of speech

Clive Sutton (1992: 78) argues that the 'figures of speech' that:

> ...emerge in the creative scientific imagination include *metaphors*, such as Darwin's *tree of life*, and slightly more cautious *similes*, such as Hutton's view of the land mass as being *like the body of an animal*. The initial effect of such figuring is to tease the mind into action as one senses a tension and strange interaction of thought in the new use of language. It often leads to the elaboration of the figure into a *model* in which some of the points of

interaction are spelled out, or into a very explicit *analogy* which can be analyzed point by point as a comparison.

Metaphors, similes, and parables (i.e. narrative metaphors) are all 'figures of speech'. As these become increasingly explicit and elaborated a simile can form the basis for an analogy, a metaphor for a model, and a parable for an allegory. Metaphors, similes, and models are tools in science for trying to establish what is happening by gaining fresh insights.

A simile resembles a metaphor in being a figure of speech. However, similes are usually identified syntactically by the presence of 'like' or 'as' (e.g. as brave as a lion).

Sutton (1993) suggests that when multiple points of detailed, and explicit comparison are expected or made a simile becomes an analogy. Examples of analogies in science include:
1. Newton likening the moon to a ball thrown so hard that its downward fall misses the earth and it passes into orbit.
2. Galileo comparing the moon (if it were to fall out of its orbit) to a rock dropped from the mast of a moving ship.
3. The hydraulic model of an electric circuit.
4. The analogy between the propagation of sound in air and the propagation of waves in water.
5. Rutherford comparing the atom to the solar system
6. The weak interaction between elementary particles being likened to a field induced by a weak uncharged electric current.
7. J.J. Thompson likening an atom to a mound of raisin pudding.
8. The analogy between nuclear fission and the division of a liquid drop into two smaller drops.
9. The analogy noted by Kelvin between electrostatic attraction and the conduction of heat.

The importance of analogies to an understanding of scientific concepts and to an understanding of the nature of science was emphasised by the physicist Robert Oppenheimer (1955):

> Analogy is an indispensable and inevitable tool for scientific progress - Whether we talk of discovery or invention, analogy is inevitable in human thought, because we come to new things in science with what equipment we have, which is how we have learned to think, and above all, how we have learned to think about the relatedness of things. We cannot, coming into something new, deal with it except on the basis of the familiar and the old-fashioned.

4. Metaphors

> Physical science is a metaphor with which the scientist, like the poet, creates and extends meaning and value in the quest for understanding and purpose.
> Jones (1982: ix)

The study of metaphor has long been with us. Aristotle, for instance, pointed out the cognitive importance of metaphor:

> But the greatest thing, by far, is to be a master of metaphor. It is the one thing that cannot be learnt from others; and it is also a sign of genius since a good metaphor implies an intuitive perception of similarity of dissimilars. Through resemblance, metaphor makes things clearer.
> Aristotle (*Poetics*, translated W.D. Ross, 1459 5-7)

Historically beliefs in scientific realism and positivism have resulted in the metaphor being viewed as being contrary to the aims of science as it was argued that it did not create the

relationship between things, but simply enlarged upon what was felt to be there already. Paul Muscari (1988), however, points out that:

> ...the metaphor's condition has taken a turn for the better. Certainly the recognition (1) that science is not clearly based on direct observational and language independent procedures; (2) that scientific terms change their meaning with the advent of new theory; and (3) that the contingency of the association between internal physical theory and internal experience precludes unmediated representation, has done much to re-establish the metaphor in the approved registry of the scientific community.

The theoretical literature on 'metaphor' is large and varied. Nietzsche argued that initially representation is metaphorical, then the temporary status of the metaphor is changed (it dies) and the status of the representation is raised to being classified as a member of the class of 'truths' As Soyland (1992: 97) points out what disappears in this process is the social, practical circumstances in which the original meaning was generated. Heidegger emphasised that the process of labelling something as 'true' is always one that is open to further negotiation. In addition The philosopher Jacques Derrida points out that in defining metaphor more metaphors are always implicated. For instance, in appealing to statements being clear and not obscure, the terms 'clear' and 'obscure' rely on metaphors involving light (from the Sun) and looking (Ricoeur, 1978: 289). A 'literal' definition of metaphor is therefore, arguably, impossible.

The use of the term 'metaphor' as a term to be constrasted with 'literal' enters into a metaphysical debate - it relies on a distinction between 'words' and 'meanings'. Wittgenstein suggested (or assumed) that metaphor is the re-description of some literal description. A sentence would be a metaphor, according to Wittgenstein, if it were possible to translate it into a literal sentence.

Max Black (1962: 31) labelled this idea the 'substitution view' as it holds that substitution of the literal for the metaphorical would communicate the same meaning. To adopt a substitution view would be to hold that understanding a metaphor is like deciphering a code or unravelling a riddle. Black argued instead for an 'interaction view' of metaphor by proposing that metaphors function, partly, by activating a 'system of associated implications' (Black 1962: 44). For instance, to say that 'man is like a wolf' is to say something about both men and wolves (see Mary Hesse, 1980).

Nietzsche suggested that truths are a collection of worn out metaphors. Maintaining something as being true would, therefore, be a matter of discursive practice. Heidegger argued that investing a proposition with truth is a social act. Derrida can be used to argue that attempts to define metaphors will always implicate further metaphors; arriving at a 'literal' definition of metaphor is not possible. Metaphors will always be involved in the creation of new meanings, in describing something new 'things are raised up' into a realm of literal discourse. Words can be regarded as discursive tools with context-dependent functions (Rorty, 1989). A scientist uses such tools to describe an object of enquiry.

Metaphor is of importance in literature, philosophy, and in science. Metaphor in science has played an important role in the development of new theories. Metaphors (often confusingly used as a broad label encompassing similes, analogies and models) have been regarded as agents for cognitive change. What are metaphors? How do they work? Why are metaphors necessary? Why are some 'better' than others?

In contemporary philosophy of language the debate on the nature of metaphors focusses initially on 'meaning'. 'Semantic' theories place metaphorical meaning in *langue*, the language system. Such meaning is viewed as a complex semantic property of phrases or sentences. According to this approach the cognitive potential of metaphor lies in the embodiment of a novel thought or proposition within this special semantic content. In contrast to this, 'pragmatic' theories place metaphorical meaning in *parole*, i.e. as a property of specific,

contextualised utterances. From this viewpoint the cognitive potential of metaphor lies not in the linguistic representation of a thought but in evoking a particular imaginative or intellectual response.

In a current semantic theory, Max Black (1955) has argued that the terms in a metaphor *interact* by giving rise to and 'filtering' systems of association. This interaction (described by I. A. Richards as 'interanimation' and by Monroe Beardsley as 'tension') generates a novel semantic content which goes beyond the literal meanings of the metaphor's separate parts. This approach appeals to language-users empirical *beliefs* , over and above the meanings of words, in the creation of metaphorical meaning.

Answering the question of how do metaphors work requires a theory of meaning and a theory of mind (Janet Martin and Rom Harré, 1982). The answer as to why metaphors are necessary is 'simply' that metaphors are necessary in order to enable people to say what they mean, as individuals can conceive more than they can at present say. The etymology of the term 'metaphor' implies the idea of 'transfer'. Martin and Harré (1982) suggest that both the substitution and Gestalt 'theories of metaphor' are largely theories on the nature of the transfer or the comparison that a metaphor effects. They quote Richards (1965: 90) who points out that basic to substitution theories is 'a sort of happy extra trick with words, ... a grace or ornament, or *added* power of language, not its constitutive form'. From this viewpoint comes the idea that metaphor is a kind of comparison, a condensed simile, or a way of saying what could be said literally, and therefore, rooted in experience. Physics, however, contains assertions about features of the world that are beyond all possible experience. Adherents of Gestalt theories assert that what can be expressed by metaphor cannot be expressed in any other way.

Students use language that they have associated with previous experiences to explain or describe unfamiliar or new phenomena. As Black (1977) and Lakoff and Johnson (1980) have argued metaphors and analogies enable abstract ideas to be expressed by grounding them in concrete experiences. Flick (1991) suggests that:

> ...students reason *from* their current understanding of bulk properties of water *to* the molecular nature of matter introduced as new idea. By analogy to melting ice, students infer that molecular "particles" must themselves melt into a liquid. The smallness of particles is perceived to be similar to the shrinking of melting ice and a concept of heat as "hot" to the touch is the melting agent. This line of reasoning is fundamentally conservative.

Martin and Harré (1982) argue that science makes assertions about features of the world that lie beyond any direct experience. Metaphor provides a means for such assertions that is meaningful and is able to provoke a novel meaning. The metaphor is able to conjure multiple perspectives. They build on I. A. Richards (1965) emphasis on metaphor as an interaction of *thoughts* and propose the following definition of a metaphor:

> Metaphor is a figure of speech in which one entity or state of affairs is spoken of in terms which are seen as being appropriate to another.
> Martin and Harré (1982: 96)

In other words, a metaphor is a figure of speech, while a model is a non-linguistic analogue (i.e. it is viewed with respect to its relationship to some other object or state of affairs). Suppose the image of a fluid is functioning as a model of a conception of the nature of electricity. Metaphorical language based on this fluid model would involve, say, the term 'rate of flow' of an 'electrical current'. Models and metaphors are, therefore closely linked.

Mary Hesse (1966) argues that a metaphor contains a large number of positive analogies (of varying degrees of similarity), and a number of neutral analogies. In addition a metaphor provokes by being obviously 'absurd' an 'as is' relation, enabling relationships to be explored.

'Dead' (or as Sutton prefers 'dormant') metaphors are those where the original element of absurdity has been forgotten, and the metaphor is viewed as a simple propositional statement.

The analogy confers 'understanding' by using relational constructs such as 'orbiting' with unfamiliar objects, e.g. electrons and the nucleus (Flick, 1991; Thiele and Treagust; 1995; Harrison and Treagust, 1996). Duit (1991) explains the distinction between analogies and metaphors:

> An analogy *explicitly* compares the structures of two domains; it indicates identity of parts of structures. A metaphor compares *implicitly*, highlighting features or relational qualities that do not coincide in two domains.

Gentner (1986) argues that the formal use of an analogy involves the cognitive mapping of relationships among objects in one domain of knowledge to another. Rutherford's solar system analogy of the hydrogen atom implies that the nucleus and the electrons are in relation to one another as the sun is to the planets. In Gentner's (1986) 'structure-mapping' theory of analogy, the nucleus is not expected to assume the attributes of the sun, and the electrons are not expected to resemble the planets in a literal sense. The analogy invokes understanding by using relational constructs such as 'orbiting' with unfamiliar objects (e.g. electron and nucleus). Structure-mapping theory proposes that for the correct mapping of an analogy:
1. Relations between objects are mapped from the *base* (solar system) to the *target* (atomic structure), and object attributes are discarded. It would not be expected that the nucleus is hotter than the electrons nor would it be expected to be yellow.
2. Which relations are mapped is determined by higher order relations, and these limit the possible choices. An important constraining relation would be 'cause'. The planet is seen to orbit the sun *because* of the gravitational attraction between the sun and the planet.

5. Models

> ...when they come to model Heav'n
> And calculate the Starrs, how they will weild
> The mightie frame, how build, unbuild, contrive
> To save appearances...
> Milton, *Paradise Lost* VIII, 79-82.

Underlying the nature of physics is the concept of model. Modelling is a fundamental aspect of 'doing' physics (Fürth, 1969; Lind, 1980; Redhead, 1980). An appreciation of physics, therefore, inherently involves an understanding of the role and the nature of models. There are numerous definitions of 'model' and of 'modelling process' in the literature (see d'Espagnat, 1983; Duit, 1991; Duit and Glynn, 1996; Harré, 1960, 1970; Hesse, 1954, 1966; Leatherdale, 1974). There is a distinction between mental and conceptual models, different kinds of models and conceptualisations (Norman, 1983). The following quotations provide some definitions of 'model' , and illustrate the diversity of opinions in the literature:

> ...a simplified representation of a phenomenon which concentrates attention on specific aspects of it thus facilitating scientific enquiry.
> Ingham and Gilbert (1991)

> A model is a surrogate object, a mental and/or conceptual representation of a real thing.
> Andaloro, Donzelli, and Sperandeo-Mineo (1991)

> A model is a representation of an object, event, or idea.
> Gilbert (1994)

> ...a conceptual model is defined as words and/or diagrams that are intended to help learners build mental models of the system being studied; a conceptual model highlights the major objects and actions in a system as well as the causal relations among them.
> Mayer (1989)

A *model*, generally, might be considered to be the representation or the outcome of the transfer of some aspects of the *source* of the model (from where it is derived) to that which is being described, i.e. to the *target* of the model. For instance the source of the Bohr-Rutherford model of the atom is the planetary system (Leatherdale, 1974: 53).

In the inductivist view of the nature of science, in which explanatory theories emerge from a review of large amounts of data, models are regarded as merely summaries of data. This view is now largely argued against by most philosophers of science (Hodson, 1992). Leatherdale (1974) describes a tendency to call certain theories 'models', e.g. the 'Bohr-Rutherford model' of the atom. Rom Harré (1978) distinguishes between 'theories' and 'models' by suggesting that a phenomenon in nature shows some observed behaviour because of the operation of a causal mechanism. A theory is proposed for the nature of that mechanism, and an associated model of the structure by or through which the mechanism operates. This is obtained by using an analogy or metaphor from the source of the model. On this viewpoint a model is a visualisable representation of the structure through which a theory might operate. The development of science consists of the construction of models, and the consequent development of theories.

Norman (1983: 7) makes useful distinctions between:

> ...a target system (that which exists in common experience), a conceptual model of the target system (the simplified model which is socially agreed by those scientists with a research interest in the target system), an individual's private, and probably transient, mental model of the target system (which may, or may not, have any relationship to the conceptual model), and the (social) scientists' (the researcher's) conceptualization of that mental model.

The research literature suggests that all models start as (private) mental models. Some mental models in science will through description and extensive use survive to become publicly available conceptual models.

Leatherdale (1974: 50) in discussing the vast and complex range of models in the literature remarks:

> Even disregarding the complex taxonomy of models proposed by Harré in *The Principles of Scientific Thinking*, where he distinguishes eight or nine different kinds of model (giving them such names as paramorphs, homeomorphs, teleiomorphs, etc.), there are a large number of different kinds of model mentioned and discussed in the literature on models; as the following sample indicates: 'logical', 'analogue' (used as an adjective), 'functional', 'mathematical', 'theoretical', 'physical', 'formal', 'material', 'archaic', 'auxiliary', 'main', '*post hoc*', 'complementary', 'phenomenological', 'simplifying', 'abstractive', 'structural'.

Peter Achinstein (1968), for instance, distinguishes between three broad types of model in science: the representational model, the theoretical model, and the imaginary model. Neelamkavil (1987) has suggested that models can be classified as physical, symbolic, and mental models. Ingham and Gilbert (1991: 193) quote Max Black (1962) as classifying models into five types:

Scale models, which are 'likenesses of material objects, systems or processes, whether real or imaginary, that preserve relative proportions'.
Analogue models, which represent 'some material object, system or process, designed to produce as faithfully as possible in some new medium the structure or web of relationship in the original'.
Mathematical models, which are of situations 'that can be summarised in, or represented by, a mathematical equation'.
Theoretical models, which involve 'the production of some concretised representation of a phenomenon, which can be applied to the study of the phenomenon without making theoretical assumptions about it.'
Archetype models, which are 'a systematic repertoire of ideas by means of which a given thinker describes, by analogical extensions, some domain to which these ideas do not immediately and literally apply.'

Finegold and Smit (1993: 19), following a literature survey, suggested the following range of views on models:

Models are constructions of the human mind and are temporary by nature.
Models in science are analogues of things and processes.
The two main uses of models in science are, (1) Heuristic - to simplify a phenomenon or make it easier to deal with; and (2) Explanatory - to explain the unknown mechanism which is responsible for the phenomenon.
The models utilized in physics are not pictures of the underlying reality but are viewed as representations of real entities.
An important role is played by models in the acquisition of knowledge about nature.
A clear distinction is made between a model and a theory.
Ideally a theory should contain the description of a plausible model, modelled on some thing, material, or process which is already well understood.

Models help the physicist to predict, describe and explain natural phenomena, particles and structures. The descriptions are never complete and different models can be used to describe the same entity.

Physicists can define a 'gravitational field', but does a gravitational field have any reality beyond its definition? Is it something physical or is it a mathematical fiction? The distinction is not as clear-cut as it may seem. As Richard Feynman (1966: 707) expressed it:

> Many different physical ideas can describe the same physical reality. Thus, classical electrodynamics can be described by a field view, or an action at a distance view, etc. Originally, Maxwell filled space with idler wheels, and Faraday with field lines, but somehow the Maxwell equations themselves are pristine and independent of the elaboration of words attempting a physical description. The only true physical description is ... the way the equations are to be used in describing experimental observations.

There is a feeling that something can be 'understood' if it can be pictured as, say, wheels and levers fitting together. The development of twentieth century physics has involved a movement away from visualisable models towards abstract mathematical models. At the microscopic level 'physical reality' cannot be directly perceived by the senses. As a consequence it is not intrinsically knowable (in the same sense) as macroscopic reality. It can however be approached at an inferential level using measurements from macroscopic instruments. Physical models based upon macroscopic experience suggest analogies. Mathematical models can be suggested by physical models (and vice-versa). These usually represent a further simplification for mathematical convenience.

6. Research into students' conceptions

In introducing the idea of cognitive models Kenneth Craik (1943: 13) stressed the use of models in thinking:

> If the organism carries a "small-scale model" of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and future, and in every way to react in a much fuller, safer, and more competent manner to the emergencies which face it.

Joan Bliss (1995: 166) points out that teaching physics is a 'matter of conveying mental models of science'. Mental models refer to students' personal knowledge while conceptual models refer to scientifically accepted knowledge (Norman, 1983). Gentner and Stevens (1983) contain several cognitive studies based on the premise that the development of mental models is essential in order to understand the physical world. Bliss and Ogborn (1994: 8) also point out that:

> Current theories in cognitive science indicate the importance of mental models (Gentner & Stevens, 1983; Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991) and point (as does Piaget's theory) to the crucial role in reasoning of the mental manipulation of imagined objects.

The term 'physical intuition' is used to describe the ability to construct such mental models. Cognitive development is described as the development of mental modelling abilities. Mental models are both a method of representing and a way of organising knowledge. The student's mental model of a system may be incomplete, confused and subject to sudden change (Redish, 1994). It may not even be internally consistent. However the possession of a model enables the student to save mental effort in coming to terms with a problem. As Arnold (1992) points out the model summarises the student's beliefs about a system, however unjustified they may be in scientific terms. The aim of the model is to enable predictions to be made about the likely future behaviour of a system. The student is unlikely to be concerned about aspects of the model that do not make sense.

Teaching and learning involves the construction by the student of mental models for entities not perceived directly, e.g. light (quanta of light), electric current (electrons), particles of matter (atoms). This modelling process is complex as it requires students to construct and use certain entities (these may be sets of objects or systems), describe these entities in exact ways using certain parameters (e.g. mass, volume, temperature change), and account for the processes of interaction between the parameters by describing relationships between them (using inventions such as force, heat, and electric current).

Perhaps not surprisingly the building of such complex models requires considerable effort and time from the student. As Rom Harrè (1961: 56) has said concerning models:

> ...they carry the picture with which everyone, schoolboy, student, engineer and research worker, operates in dealing with problems in his field. You may deny that you have a model and be as positivistic as you like, but while the standard expressions continue to be used you cannot but have a picture.

Max Born (1953/4: 140) in an article entitled *Physical Reality* remarks:

> All great discoveries in experimental physics have been due to the intuition of men who have made free use of models, which were for them not products of the imagination, but representations of real things.
> ...[Niels Bohr] has repeatedly and emphatically said that it is impossible to describe any actual experiment without using ordinary language and the concepts of naive realism.

Thagard (1992), however, points out there is the problem of 'worn-out analogies interfering with the acquisition of new ones'. The Bohr model of the atom is introduced by analogy to the solar system, but the model of orbits that is acquired can get in the way of the later incorporation of the concepts of quantum mechanics.

On the basis of their everyday experience people develop naive theories or alternative conceptions that can provide not only descriptions of, but causal explanations of, phenomena (e.g. McCloskey, 1983). These alternative conceptions significantly influence student learning (e.g. Clement, 1983; Viennot, 1979). Such research has stimulated the development of teaching strategies that encourage students to a greater self-awareness of their own models, to make predictions based on them and to make comparisons between their own and accepted scientific models (Clement, 1983). As Maureen Pope and John Gilbert (1983) point out science education is concerned with connecting explanation and understanding between teachers and students. Rosalind Driver (1983: 24) suggests that when talking science children make use of analogy:

> Faced with a normal phenomenon, pupils are searching to find familiar events to which they relate this new experience. They try to interpret the unfamiliar by analogy with familiar experiences.

In surveying previous research on students' understanding of the nature of models there seems to have been relatively little research carried out in the UK on how A-level students conceptualise the nature of models, e.g. what models are for, how (and by whom) they are made, under what conditions (if any) they should be changed, whether or not there can be multiple models for the same 'thing', and what models actually represent.

In Germany Petri and Niedderer (1995) carried out an investigation, using interviews, of how a single student came to terms with quantum physics. With regard to the role of models in physics the student, Carl, commented:

> *A model is a conception of something (e.g. the model of the atom). Often it also is a simplification: E.g., free falling does not exist in nature, thus one "builds up" a model in mind that optimizes the conditions and processes.*
> Petri and Niedderer (1995: 9) [italics in the original]

The student is adhering to a correspondence between physical models and reality. The importance of investigating not just students' ideas of quantum physics, but also students' ideas of models and the 'reality' accorded to entities is emphasised by Petri and Niedderer (1995: 9) when they argue:

> Changing (expanding) Carl's model of the atom means more than changing a conception of a moving particle into the conception of a stationary charge cloud. It requires to change his view of the world, part of his personal identity and conviction.

Canadian high school students were asked to respond to the following two statements concerning the nature of models by indicating whether they agreed with it and to explain the reasons for the choice:

> 13.1 Many scientific models (such as a model of the atom or of DNA) are metaphors or useful stories; we should not believe that these models are duplicates of reality.
> 13.2 Many scientific models (such as a model of the atom or of DNA) are accurate duplicates of reality.
> Aikenhead (1987: 463)

Aikenhead (1987: 463) describes the analysis of students' responses and the following categories that were generated:

A. Within their limitations, models are helpful for learning and explaining.
B. Models change with time and with the state of our knowledge, like theories do.
C. Models can represent certain properties of reality that scientists see.
D. Models help us understand by duplicating a part of reality.
E. A model's accuracy cannot be taken for granted.
F. Models are true to life. That is their purpose.
G. Many models duplicate reality because much scientific evidence has proven then true.
H. Authorities say they are true, so they must be true.

Grosslight, Unger and Jay (1991), in the USA, found that the (55) high school students they interviewed had conceptions of models that seemed to be consistent with having a naive realist epistemology. They did find, however, that under the influence of teaching their ideas became more sophisticated, including realising that models are designed for particular purposes. The (4) university teachers interviewed drew a distinction between abstract and physical models, and were aware of the ways that models are used for constructing and testing ideas. Students were assigned to 3 levels (representing an increasing awareness of the nature of models) on the basis of scores on six dimensions: the role of ideas, the use of symbols, the role of the modeller, role of the model in communication, the notion of testing, multiplicity in model building. They suggesting that students needed more experience and discussion on the nature and roles of models (see also Brown and Steinberg, 1993; Hardwicke, 1995a, 1995b).

In the UK Ingham and Gilbert (1991: 197) interviewed 45 chemistry undergraduate and postgraduate students with regard to the uses of analogue models and constructed the following students' conceptions of models:

(A) The model as a self-consistent system which corresponds to reality.
(B) The model as a way of explaining or justifying a theory which is thought to be a permanent part of the chemist's repertoire.
(C) The model as an evolving link between the macro- and micro-levels.
(D) The model as a way of achieving the understanding that others require.
(E) The model as a way of achieving a commonality of understanding between chemists.
(F) The model as a way of engaging the interest and involvement of others in a particular phenomenon.

The previous research on students' conceptions of the nature of models is consistent with a survey of the literature on models carried out by Finegold and Smit (1993: 7) when they summarised the various views as a series of statements:

1. All models are creations of the human intellect.
2. All models are representations. (some are purely visual, some can be seen and felt).
3. Any representation that one makes of an object, of a structure, or of a process is called a model.
4. Models exist in nature.
5. All models are mental images (existing only in the human mind).
6. Models are aids that are used to obtain knowledge of nature.
7. A model always provides a complete description of the object, structure or process in nature that it models.
8. A model is formulated using facts obtained by experiment and/or observation.
9. The terms model and theory are synonymous.

10. The only function of models in science is in teaching.
11. Models are of a temporary nature. With the increase of knowledge a model may become obsolete or useless and either adapted or replaced by another model.
12. A scientist always has more knowledge of an object, process or structure that is represented by the model itself.
13. An important function of any model is to describe something (an object, a structure, or a process) in nature.
14. Models play an important role in the explanation of phenomena.
15. Models can be used to predict phenomena, structures, or processes that have not previously been observed.

7. Research methodology

The literature survey suggests that compared to the research that has been carried out on identifying the alternative conceptions held by students in particular domains (e.g. electricity, mechanics etc.) very little work has been carried out on how aware A-level students are of the nature of models. In other words this study needs to try to confirm if students' conceptions of the nature of models in the UK are similar to those previously identified in the literature. In addition the relationship between visualisability and models needs to be explored. The ideas that students have for the use of multiple models for the same phenomena or object (e.g. the billiard ball and the electron-nucleus models of the atom), and their explanations for reconciling the use of multiple models also need to be investigated.

At present in England and Wales upper secondary school students (ages 16-18) wishing to read for a physical science degree at university will follow the two year Advanced Level Physics course. The research project as a whole is exploring students' conceptions of quantum physics, models, and the epistemological and ontological status of theoretical entities. The study described here reports on some of the findings with regard to students' ideas of photons, the nature of models and analogies, multiple models of light and the atom.

The research instrument consisted of a semi-structured questionnaire completed by A-level Physics students (N = 83) in three secondary schools (in the UK) in October 1994. The questionnaire utilised open and closed questions, drawings of particular situations, and attitude scales[1]. Physics textbooks, examination questions, the research literature, and the researcher's own teaching experience were used to initially construct the questions. Discussions with expert evaluators were then used to refine them.

The questionnaire utilised directed or free questions, and students were encouraged to write freely in their own words. This approach enabled a considerable amount of significant data to be acquired in a relatively short time. The use of a questionnaire maximised the sample size. A large sample size enabled a wide range of students' writing, and consequently a wide spread of students' conceptions to be obtained.

8. Data analysis

How best to analyse data is a difficult issue. The object-domain is language (in this case in the form of text), but language not as a physical object measurable as sound waves but language as shared meaning. The researcher is therefore automatically a participant observer. As Ricoeur (1981) points out the realist position usually adopted by researchers in the physical sciences is not possible in the analysis of language. The meaning of a word or utterance in a discourse is internally related to other words and utterances in an unlimited and dynamic way and so can never be rigorously defined (Derrida, 1973). Category analyses can distort the reality of data. Edwards and Mercer (1987: 4) suggest that however 'scientific' analyses based on codings seem to be, they are always dependent on prior interpretations in selecting the coding scheme to be used and in categorising sentences or utterances.

[1] See the *Appendix* for a copy of the questionnaire.

Bearing the previous considerations in mind some numerical analysis of the data through codings was undertaken to supplement and support the qualitative interpretation. Two important preliminaries to the qualitative analysis were: gaining an intimate knowledge of the data as a whole, and building up an 'interpretive web' through reading relevant theory and previous research.

An interpretative methodology was adopted for the construction of meaning from the responses to the open questions in the questionnaire. A database program (FilemakerPro) was used to create a separate file card for each response to a question. Once the large quantity of data had been entered then these 'cards' were sorted to collate all the responses for each question from all of the questionnaires, enabling an overview to be obtained. An iterative approach was then adopted to identify or construct students' conceptions from the data. The principal concern was that the qualitative analysis should be rigorous, and systematic.

Following an initial read-through of the collated responses to a particular question the types of responses were noted. This generated an initial list of possible categories of responses. The procedure was then repeated more finely to generate categories to cover all of the students' responses. An EXCEL spreadsheet was set up and using the statistical program SPSS (Statistical Package for the Social Sciences), on the Macintosh computer, frequency distributions of responses for each question were obtained. The final stage was the production of a descriptive summary of the overall findings, which included quotations from the questionnaires to illustrate particular conceptions. It should be borne in mind that the summary statements characterising students' conceptions represent a much reduced description of students' responses to questions. As Watts (1982: 14) commented on the 'pithy summary statements' he used to characterise children's conceptions of energy:

> The framework here came from no one pupil. They have been placed together from the implicit and explicit conceptions used by the children during the course of the interviews...The frameworks are not intended as discrete and mutually exclusive categories of interview responses. This is an important point. The expressions youngsters use can be classified in a number of ways. In this case their words are being taken as evidence for particular ways of treating the term energy.

The principal problem of interpretive studies attempting to elicit students' conceptions is the hermeneutic circle - the researcher's knowledge of students' conceptions is dependent on the researcher's constructions, which are based on the researcher's conceptions (Johansson, Marton and Svensson, 1985; Jung, 1987; Kesidou and Duit, 1993).

The validity of the researcher's construction of students' conceptions resulting from the researcher's interpretation of students' responses to the open questions is established by providing information to allow the reader to consider whether they would come to the same conclusions concerning students' conceptions.

The validity of the generated conceptions is underscored by the complementary use of qualitative and quantitative techniques (Reichardt and Cook, 1979). As an additional form of 'triangulation' peer discussion was used to enhance validity.

9. Students' conceptions

9.1 Students' conceptions of models

In order to probe students' ideas they were asked to explain what a model is, to give examples of models, and to indicate if they thought a model is visualisable[2]. Students' responses to the question were interpreted as giving rise to the following principal conceptions about the nature of models:

---

[2] See the *Appendix* for the questions asked (including question B01 on the nature of models).

1. Scaled representation
2. Relationship between model and theory
3. Visual representation
4. Aid to communication
5. Mental construction
6. Explanatory role
7. Formation of models

Nearly a fifth of the students (~20%) thought that a model refers to a **scaled representation**. For instance, a 'scale model' in which there is no difference between a technical or construction model and a scientific model:

> A model is an exact copy of something that occurs or is built in real life, but it [is] made larger or smaller. A different material may be used to build the model that what the object is made of.
> B01(a)/44[3]

Within this conception for some students there is an explicit implication of completeness, that is, a model provides a complete description of the object or process in nature that it models:

> A model can be a literal copy of what we can see, or a[n] image of something we can see but have the knowledge to imagine what it is like.
> B01(a)/39

> A replica or scaled down version of something which will behave in the same way as the original only on a smaller scale or it is a replica of something so small it is invisible to the human eye. Made larger so we can understand it better.
> B01(a)/58

Again within the same broad conception there is an implication by some students that although it is a scaled up or down copy it may have been simplified, i.e. the scientist may have more knowledge of the object or process than is represented by the model itself:

> A model is a scaled up or down, simplified version of a complex or hard to picture situation. They can be used to illustrate what happens inside something or what something looks like, i.e. the solar system or an atom.
> B01(a)/42

Another viewpoint, held by ~ 16% of students, is that a model **depicts or describes a theory**:

> A model is a way of describing a scientific theory, that is possibly connected with an image, which helps to explain why something happens.
> B01(a)/14

> A model is something that scientists use to relate theories etc. to something we know. Examples include things that are too small to see, like an atom. They are generally used to simplify things to enable us to understand.
> B01(a)/51

The principal viewpoint (held by nearly one-third of the students) was that a model is a **visual representation** of the abstract and the unseen:

> A model is an idea of what something looks like, if the something is too small to see.

[3] The notation indicates that this is the response to question B01(a) by student number 44.

B01(a)/36

A 'model' is something which exist yet is not regularly seen e.g. current and needs to be interpreted as something we can picture/see.
B01(a)/50

In response to an open question[4] as to whether or not a model necessarily has a picture or image associated with it a majority of the students thought a model is (or should be) visualisable (54% versus 39%).

A small number of students (~4%) suggested that students are **aids in communicating ideas**:

A way to demonstrate a principle. It helps to communicate an idea as simply as possible.
B01(a)/54

A model aids the scientist in communicating ideas.
B01(a)/53

Another perception of models is that models are **constructions of the human mind** or mental images (held by ~4% of students):

A model is an idea that is someones mind to represent something physical which can't be shown.
B01(a)/6

A model is an idea that you have in your mind that you can make into a 'model' so as you can physically see it.
B01(a)/8

Another conceptions refers to the **explanatory role** of models. A small proportion of students (~8%) thought that a model is a simulation of a situation (equations, computer, words):

A model is usually a model which describes a circumstance or action, such as in momentum when two cars crash. They represent these with words, writing or simulation.
B01(a)/64

A simplified version of a situation, either experimentally or mathematically to obtain results which are close to correct, but can be improved by further refinement of the model. They are used in physics to find results for practical experiments.
B01(a)/74

A variation on this conception, held by ~8% of students, is that a model has a heuristic purpose (to simplify a phenomenon):

The model is a simplified structure that can be used to relate calculations to the real world. This is much simpler than trying to think of the structure as it really is. It is usually used to picture something that is unable to be seen by a human eye i.e. electrons in a field round an atom.
B01(a)/49

A model is the idea of what something could look like as a model, to help us understand better e.g. atoms and molecular structure.
B01(a)/2

---

[4] Question on models in the questionnaire:
B01(c) Does a model necessarily have a picture or image associated with it?

Only a very few students (~2%) explicitly suggested **how models come to be formed**, by observation or analogy, although it is implied by the large numbers of students who adhered to models as scaled representations of objects or processes:

> A method where, by analogy, something in everyday life, or something already known to us, is used to explain something new or exceedingly difficult.
> B01(a)/38

> A model is a representation of something from the real world which is simplified to allow easy application of science.
> B01(a)/12

In the following sections where students' conceptions of multiple models of the atom are described another conception of the formation of models is made explicit. That is their temporary nature, as knowledge increases may cause models to become obsolete or be replaced by an adapted model.

To complement the open questions on models the questionnaire used in study (S3) also asked the students to indicate if they agreed or disagreed (using a 5-point response scale) to a series of statements on models (see Table 1). A substantial majority of students indicated that models are thought up to represent (or describe) an object or process using facts obtained by experiment and observation in order to obtain knowledge of nature. Furthermore models have an important explanatory or predictive role with regard to phenomena. A model may be adapted or replaced by another model as more knowledge becomes available. Students on the other hand disagreed with the assertion that all models are mental images, that models always provide a complete description of the object or process, or that the only function of models is in teaching. Opinions were more or less evenly divided as to whether or not models exist in nature, whether the scientist (modeller) has more knowledge than that represented by the model, and whether there is a difference between models and theories. Students' responses to these statements are therefore generally consistent with the interpretation of the responses to the open questions.

Table 1: Students' responses to statements on models

Statements	% of students who agree with statement	% of students who disagree with statement
C01 All models are creations of the human intellect.	72.3	14.4
C02 All models are representations. (Some are purely visual, some can be seen and felt).	78.3	6.0
C03 Any representation that one makes of an object, of a structure, or of a process is called a model.	57.8	15.6
C04 Models exist in nature.	27.7	33.7
C05 All models are mental images (existing only in the human mind).	31.4	53.1
C06 Models are aids that are used to obtain knowledge of nature.	68.7	7.2
C07 A model always provides a complete description of the object, structure or process in nature that it models.	8.4	72.3
C08 A model is formulated using facts obtained by experiment and/or observation.	71.1	8.4
C09 The terms model and theory are interchangeable.	26.5	31.3
C10 The only function of models in science is in teaching.	18.0	61.5
C11 Models are of a temporary nature. With the increase of knowledge a model may become obsolete or useless and either adapted or replaced by another model.	69.9	12.0
C12 A scientist always has more knowledge of an object, process or structure than is represented by the model itself.	24.1	31.3
C13 An important function of any model is to describe something (an object, a structure, or a process) in nature.	67.5	7.2
C14 Models play an important role in the explanation of phenomena.	56.6	6.0
C15 Models can be used to predict phenomena, structures or processes that have not previously been observed.	51.8	12.0

BEST COPY AVAILABLE

9.2 Students' conceptions of the nature of analogies

The students were presented with an open question asking about analogies in order to investigate their ideas about analogies and how they differ from models[5]. In analysing students' responses a number of viewpoints on the nature of analogies emerge:

1. Similarity
2. Aid to understanding
3. Aid to visualisation
4. A way of thinking or 'seeing'

Nearly two-thirds of the students regard an analogy as referring to a **similarity** or likeness between properties or behaviour:

> Analogy - two or more descriptions being linked by certain similarities ... are said to be 'analogous' to each other.
> B02(a)/20

> Showing similarities between two things. Like capacitance and a bouncing spring with a weight on the bottom of it.
> B02(a)/23

An analogy is also viewed, by ~ 8% of students, as an example of something that **helps to understand** the phenomena:

> Using a simple, everyday example to show how a complicated example works.
> B02(a)/15

> It's a way of associating things with one other to make them easier to understand.
> B02(a)/47

A small number of students (~ 4%) suggest that an analogy is an **aid to visualisation**, by comparing something that can be seen to something that cannot:

> It is when you compare something, you cannot see to something you can. This helps you to visualise what is happening.
> B02(a)/14

> When you compare something that is difficult to picture to an everyday event.
> B02(a)/45

An analogy was also viewed by some students (~ 4%) as a way of thinking or **'seeing' a new concept**:

> It is a way of thinking. Everything falls into place when you think of light and sound behaving this way.
> B02(a)/53

> An analogy is a way of thinking about things. i.e. We cannot see sound or light as waves but if we think of them as waves, then it all "adds up".
> B02(a)/51

Comparing the various conceptions of models and analogies, the principal difference seems to be that students regard models as being more concerned with representation while analogies are viewed as being concerned with suggesting a way of 'seeing' similarities between properties or behaviour.

---

[5] See the *Appendix* for a copy of the questionnaire containing question B02 asking about analogies.

9.3 Students' conceptions of rationale for multiple models
In the kinetic theory of gases the atom is described or modelled as being like a billiard ball. In atomic physics the atom is modelled as consisting of a nucleus and electrons. A question was posed which investigated students' rationales for why there should be a number of models for the concept of the atom[6]. A number of rationales for the necessity of multiple models of the atom were obtained:
1. Different levels of explanation
2. Different aspects of phenomena
3. Different perspectives
4. Different purposes
5. Different knowledge available

Nearly a quarter of the students felt that **different levels of explanation** or detailing are required for different theories, concepts or levels of education:

> As descriptions do not have to conflict as they only vary in detail as in some theories description needed is simple but in others it needs to be complicated so different descriptions are required.
> B03(b)/22

> Things can be viewed from different levels of detail. E.g. Things can be looked at from a microscopic point of view or a macroscopic point of view.
> B03(b)/79

Another rationale (held by ~ 16% of students) is that by concentrating on **different properties or aspects of a phenomena** it is possible to have more than one description of the same thing (e.g. the billiard-ball and nucleus-electrons descriptions of the atom):

> One description describes how it acts, i.e. the atom acts as though it has a hard shell like a billiard ball whereas the other description describes what it is made of.
> B03(b)/41

> It is possible because each description could describe a different aspect of that same thing.
> B03(b)/50

There are multiple descriptions of the atom (e.g. the billiard-ball and nucleus-electrons descriptions) as **different people have differing perspectives** based on their experiences (held by ~16% of students):

> Because everyone looks at things differently so there is likely to be different descriptions from different people. Also if you are required to go into depth you may have to give a more detailed description.
> B03(b)/8

> By relating a scientific process to an analogous commonly known one, it is possible to have many different ways to describe one thing. It all depends on the experiences of the person explaining and the person learning.
> B03(b)37

Some students (~13%) suggested that **different descriptions are required for different uses**, purposes or situations:

[6] See the *Appendix* for a copy of the questionnaire containing question B03 asking about rationales for having multiple descriptions or models of the atom.

> It may be easier to think of something in very simple terms for one train of thought, but it may be necessary to think about the same thing in more complex terms for another.
> B03(b)/51

> The two descriptions are for different purposes: the first to enable (people to imagine) ball shaped objects bouncing off each other and others; the second to give an idea of the more detailed (actual) structure and to lead on to other things such as the forces between the particles.
> B03(b)/65

A small percentage of students (~8%) pointed out the temporary nature of models, i.e. the view that **description depends on the knowledge available**:

> Different people see things differently, and it is necessary to remember that as time and research progress people become more knowledgeable. It is then that you discover you have more than one description for the same thing, neither being necessarily wrong.
> B03(b)/14

> Somethings could be described in different ways as more knowledge and understanding is gained about it. Also a more complex description is different to a simple one.
> B03(b)/16

10. Conclusion

Figurative thinking lies at the heart of scientific thinking. An understanding by students of the nature of metaphors, analogies and models is essential to develop an understanding of the nature of science. The empirical results indicate the wide spread of students' conceptions of models and analogies. Further work needs to be undertaken to gain an insight into students' conceptions of the use and nature of metaphors.

11. References

Andersson, B. (1986): 'The experimental Gestalt of causation: A common core to pupils' preconceptions in science', *European Journal of Science Education*, Vol. 8, No. 2), pp.155-171.

Ausubel, D. P. (1968): *Educational Psychology* (New York: Holt, Rinehart and Winston).

Barbour, I. (1974): *Myths, Models and Paradigms: A Comparative Study in Science and Religion* (Harper and Row: New York).

Beck, B. E. F. (1978): 'The Metaphor as a Mediator Between Semantic and Analogic Modes of Thought', *Current Anthropology*, Vol. 19, No. 1, pp. 83-97.

Berggren, D. (1962): 'The Use and Abuse of Metaphor II', *Review*, December 1962, pp. 450-472.

Billow, R. M. (1981): 'Observing Spontaneous Metaphor in Children', *Journal of Experimental Child Psychology*, Vol. 31, pp. 430-445.

Black, M. (1962): *Models and Metaphors* (Cornell University Press: Ithaca, NY).

Boulter, C. J. and Gilbert, J. K. (1995): *Texts and Contexts: Framing modelling in the primary science classroom*, paper presented at the European Science Education Conference, University of Leeds (7-11 April 1995).

Brown, D. E. and Steinberg, M. S. (1993): 'Analogical models - Boon or Bane in Science Instruction?', in *Proceedings of the Third International Seminar on Misconceptions and Educational strategies in Science and Mathematics* (Misconceptions Trust: Ithaca, NY)

Claxton, G. (1997): 'Science of the times: A 2020 vision of education', in R. Levinson and J. Thomas (Eds.) *Science Today: Problem or Crisis?* (Routledge: London).

Craik, K. (1943): *The nature of explanation* (Cambridge University Press: Cambridge).

Curtis, S. and Millar, R. (1988): 'Language and Conceptual Understanding in Science: a comparison of english and Asian language speaking children', *Research in Science and Technological Education*, Vol. 6, No. 1, pp. 61-77.

Driver, R. (1981): 'Pupils' alternate frameworks in science', *European Journal of Science Education* , 3 (1), pp.93-101.

Einstein, A. and Infeld (1938): *The Evolution of Physics* (Cambridge University Press: Cambridge).

Erickson, G. (1979): 'Children's conceptions of heat and temperature', *Science Education* , Vol. 63, No. 2, pp.221-230.

Fürth, R. (1969): 'The Role of Models in Theoretical Physics', in R. S. Cohen and M. W. Wartofsky (Eds.), *Proceedings of the Boston Colloquium for the Philosophy of Science 1966/1968* (Reidel: Dordrecht).

Gerhart, M. and Russell, A. (1984): *Metaphoric Process: The Creation of Scientific and Religious Understanding* (Texas Christian University Press: Fort Worth, USA).

Gilbert, J. and Watts, D. (1983): 'Concepts, misconceptions and alternative conceptions: changing perspectives in science education', *Studies in Science Education*, Vol. 10, pp.61-98.

Hanson, N. R. (1972): *Patterns of Discovery* (Cambridge University Press: Cambridge).

Hardwicke, A. J. (1995a): 'Using molecular models to teach chemistry. Part 1 Modelling molecules', *School Science Review*, Vol. 77, No. 278, pp. 59-64.

Hardwicke, A. J. (1995b): 'Using molecular models to teach chemistry. Part 2 Using models', *School Science Review*, Vol. 77, No. 279, pp. 47-56.

Harrison, A. G. and Treagust, D. F. (1996): 'Secondary Students' Mental Models of Atoms and Molecules: Implications for Teaching Chemistry', *Science Education*, Vol. 80, No. 5, pp. 509-534.

Hesse, M. (1970): *Models and Analogies in Science* (Notre Dame Press: Notre Dame).

Hestenes, D. (1995): 'Modeling software for learning and doing physics', in C. Bernardini, C. Tarsitani, and M. Vincentini (Eds.), *Thinking physics for teaching*, pp. 25-66 (Plenum: New York).

Hewson, M. (1987): *The development of metaphoric comprehension in children aged between eight and fourteen years*, unpublished Ph D thesis ((University of Manchester).

Hill, J. and Mannheim, B. (1992): 'Language and world view', *Annual Review of Anthropology*, Vol. 21, pp. 381-406.

Holton, G. (1973): *Thematic Origins of Scientific Thought* (Harvard University Press: Cambridge).

Jones, R. S. (1982): *Physics as Metaphor* (University of Minnesota Press: Minneapolis).

Kuhn, T. S. (1970): *The Structure of Scientific Revolutions* (The University of Chicago Press: Chicago).

Lakoff, G. and Johnson, M. (1980): *Metaphors We Live By* (Chicago University Press: London)

Lind, G. (1980): 'Models in Physics: Some Pedagogical Reflections based on The History of Science', *European Journal of Science Education*, Vol. 2, No. 1, pp. 15-23.

MacCormac, E. (1976): *Metaphor and Myth in Science and Religion* (Duke University Press: Durham).

Ortony, A. (Ed) (1979): *Metaphor and Thought* (Cambridge University Press: Cambridge).

Osborne, R. and Gilbert, J. (1980): 'A Method for Investigating Concept Understanding in Science', *European Journal of Science Education*, Vol. 2, No. 3, pp. 311-321.

Pepper, S. C. (1973): 'Metaphor in Philosophy', in P. P. Wiener (Ed.) *Dictionary of the History of Ideas* , Vol. 3, pp. 196-201 (Charles Scribner's Sons: New York).

Pope, M. and Gilbert, J. (1983): 'Explanation and metaphor in some empirical questions in science education?', *European Journal of Science Education* , Vol. 5, No. 3, pp.249-261.

Richards, I. A. (1936): *The Philosophy of Rhetoric* (Oxford University Press: London).

Ricoeur, P. (1976): *Interpretation Theory: Discourse and the Surplus of Meaning* (Texas Christian University Press: Fort Worth).

Ricoeur, P. (1977): *The Rule of Metaphor: An Interdisciplinary Study* (University of Toronto Press: Toronto).

Rohrer, T. (1995): *The cognitive science of metaphor from philosophy to neuropsychology*, electronic article (available at Website: *http://metaphor.uoregon.edu/neurophl.htm*).

Rorty, R. (1980): *Philosophy and the Mirror of Nature* (Blackwell: Oxford).

Rorty, R. (1989): *Contingency, Irony, and Solidarity* (Cambridge University Press).

Sacks, S. (Ed) (1978): *On Metaphor* (The University of Chicago Press: Chicago).

Sapir, E. (1929): 'The status of linguistics as a science', *Language*, Vol. 5, pp. 207-214.

Solomon, J. (1986): 'Children's Explanations', *Oxford Review of Education*, Vol. 12, No. 1, pp. 41-51.

Soyland, A.J. (1992): *Describing psychological objects: Metaphor and rhetoric in theories of psychology*, unpublished D Phil thesis (University of Cambridge).

Sutton, C. (1992): *Words, Science and Learning* (Open University Press: Buckingham).

Sutton, C. (1993): 'Figuring Out a Scientific Understanding', *Journal of Research in Science Teaching*, Vol. 30, No .10, pp. 1215-1227.

Thiele, R. B. and Treagust, D. F. (1995): 'Analogies in chemistry textbooks', *International Journal of Science Education*, Vol. 17, No. 6, pp. 783-795.

Tolstoy, I. (1990): *The Knowledge and the Power: Reflexions on the History of Science* (Canongate: Edinburgh).

Vaihinger, H. (1935): *The Philosophy of 'As If'* (Routledge and Kegan Paul).

Wellington, J. J. (1983): 'A taxonomy of scientific words', *School Science Review*, pp. 767-772.

White, R. and Gunstone, R. (1992): *Probing Understanding* (The Falmer Press: London).

Young, R. M. (1993): 'Darwin's metaphor and the Philosophy of Science', *Science as Culture*, Vol. 16, No. 3, pp. 375-403 (accessed as an electronic document at website, http://www.shef.ac.uk/uni/academic/N-Q/psysc/staff/rmyoung/papers/paper8h.html, downloaded on April 25, 1996).

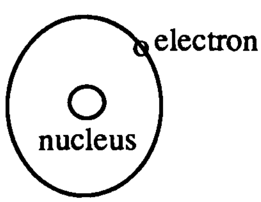
Zeidler, D. L. and Norman G. L. (1989): 'The effect of teachers' language on students' conceptions of the nature of science', *Journal of Research in Science Teaching*, Vol 26, No. 9, pp. 771-783.

Appendix: Questionnaire

Section B

The following questions are concerned with how you think language is used in Physics. Try to answer all of the questions as fully as possible.

B01 (a) Scientists often use the word '**model**'. Try to explain as fully as possible what is meant by a model, and how they are used in physics.
(b) Give three examples of models used in physics:
(c) Does a model necessarily have a picture or image associated with it?
B02 (a) There is said to be an **analogy** between sound and light as both are described as being waves. What is meant by the term '**analogy**'?
(b) Give three other examples of analogies used in physics.
B03 In the kinetic theory of gases the atom is described as being like a billiard ball. In atomic physics the atom is now said to consist of a nucleus and electrons.
(a) Is the second description better? Explain your answer as fully as possible.
(b) How is it possible to have more than one description for the same thing?
B04 In many textbooks there is a diagram like the one below, in which an electron is said to be in orbit around the nucleus of the atom:



In some science textbooks, especially chemistry textbooks, when diagrams of atoms are drawn they do not show individual electrons in orbit but describe electron orbitals or electron clouds.
Why are there two different models?
B05 When physicists talk about light being a wave are they describing a literal truth, a picture, a metaphor, a model or a vague similarity? Answer as fully as possible.
B06 (a) Write down three statements about electrons referring to models or metaphors where relevant:
B06 (b) Do you have a picture or image of an 'electron' in your head? If so, describe this image.
B06 (c) Consider the three statements below:
A The theory of electrons is only useful in making correct predictions.
B Electrons are a convenient fiction for co-ordinating the results of observations.

C Electrons really exist independently of theories.
With which statement do you most agree with? _______
Explain your choice.
B07 (a) Student A writes in an essay:

It is hard to know what light is "really" like but it is **as if** it consists of tiny particles called photons.

Student B comments that she shouldn't use the words 'as if', since light really does consist of particles. What do you think?
(b) Do you have a picture or image of a 'photon' in your head? If so, describe this image.
(c) Student C writes in response to a question that:

Light can be modelled using **both** wave and particle models.

Student D argues that you cannot use two models for the same phenomena. Light is either waves or particles, but not both. What do you think?

Section C *For each of the statements below consider to what extent you agree with it, and give it a rating on a 1 to 5 scale by circling one of the numbers:*

1 means that you **Strongly Agree** with it
2 means that you **Agree** with it
3 means that you have **No Strong Opinion** about it
4 means that you **Disagree** with it
5 means that you **Strongly Disagree** with it

Then in the space underneath each statement try to explain your answer.
Read each statement carefully and give an answer and explanation to all of the questions.

C01 All models are creations of the human intellect.
C02 All models are representations. (Some are purely visual, some can be seen and felt).
C03 Any representation that one makes of an object, of a structure, or of a process is called a model.
C04 Models exist in nature.
C05 All models are mental images (existing only in the human mind).
C06 Models are aids that are used to obtain knowledge of nature.
C07 A model always provides a complete description of the object, structure or process in nature that it models.
C08 A model is formulated using facts obtained by experiment and/or observation.
C09 The terms model and theory are interchangeable.
C10 The only function of models in science is in teaching.
C11 Models are of a temporary nature. With the increase of knowledge a model may become obsolete or useless and either adapted or replaced by another model.
C12 A scientist always has more knowledge of an object, process or structure than is represented by the model itself.
C13 An important function of any model is to describe something (an object, a structure, or a process) in nature.
C14 Models play an important role in the explanation of phenomena.
C15 Models can be used to predict phenomena, structures or processes that have not previously been observed.

SE061022

ERIC

U.S. Department of Education
Office of Educational Research and Improvement (OERI)
Educational Resources Information Center (ERIC)

REPRODUCTION RELEASE

(Specific Document)

I. DOCUMENT IDENTIFICATION:

Title: FIGURATIVE THINKING AND THE NATURE OF PHYSICS

Author(s): A. MASHHADI

Corporate Source: PAPER PRESENTED AT THE 7TH INTERNATIONAL CONFERENCE ON THINKING (SINGAPORE, 1-6 JUNE 1997)

Publication Date: 1997

II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, *Resources in Education* (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic/optical media, and sold through the ERIC Document Reproduction Service (EDRS) or other ERIC vendors. Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce and disseminate the identified document, please CHECK ONE of the following two options and sign at the bottom of the page.

☑ Check here **For Level 1 Release:** Permitting reproduction in microfiche (4" x 6" film) or other ERIC archival media (e.g., electronic or optical) *and* paper copy.

The sample sticker shown below will be affixed to all **Level 1** documents

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY

Sample

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

Level 1

The sample sticker shown below will be affixed to all **Level 2** documents

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN OTHER THAN PAPER COPY HAS BEEN GRANTED BY

Sample

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

Level 2

☐ Check here **For Level 2 Release:** Permitting reproduction in microfiche (4" x 6" film) or other ERIC archival media (e.g., electronic or optical), but *not* in paper copy.

Documents will be processed as indicated provided reproduction quality permits. If permission to reproduce is granted, but neither box is checked, documents will be processed at Level 1.

"I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce and disseminate this document as indicated above. Reproduction from the ERIC microfiche or electronic/optical media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries."

Sign here→ please

Signature: Azam Mashhadi

Printed Name/Position/Title: DR A. MASHHADI

Organization/Address: DEPT. OF EDUCATIONAL STUDIES (UNIVERSITY OF OXFORD) 15 NORHAM GARDENS OXFORD, UNITED KINGDOM

Telephone: (UK) 01865-274024

FAX: (UK) 01865-274027

E-Mail Address: azam.mashhadi@edstud.ox.ac.uk

Date: 22 Oct 1997

(over)

III. DOCUMENT AVAILABILITY INFORMATION (FROM NON-ERIC SOURCE):

If permission to reproduce is not granted to ERIC, *or*, if you wish ERIC to cite the availability of the document from another source, please provide the following information regarding the availability of the document. (ERIC will not announce a document unless it is publicly available, and a dependable source can be specified. Contributors should also be aware that ERIC selection criteria are significantly more stringent for documents that cannot be made available through EDRS.)

Publisher/Distributor:
Address:
Price:

IV. REFERRAL OF ERIC TO COPYRIGHT/REPRODUCTION RIGHTS HOLDER:

If the right to grant reproduction release is held by someone other than the addressee, please provide the appropriate name and address:

Name:
Address:

V. WHERE TO SEND THIS FORM:

Send this form to the following ERIC Clearinghouse:

However, if solicited by the ERIC Facility, or if making an unsolicited contribution to ERIC, return this form (and the document being contributed) to:

ERIC Processing and Reference Facility
1100 West Street, 2d Floor
Laurel, Maryland 20707-3598

Telephone: 301-497-4080
Toll Free: 800-799-3742
FAX: 301-953-0263
e-mail: ericfac@inet.ed.gov
WWW: http://ericfac.piccard.csc.com

(Rev. 6/96)